

A Novel Manufacturing Process of Lightweight Automotive Seats - Integration of Additive Manufacturing and Reinforced Polymer Composite

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06/23/2021

Project ID#: mat210

ORNL is managed by UT-Battelle, LLC
for the US Department of Energy

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Overview

Timeline

- Project start date: Feb 2020
- Project end date: Feb 2022
- Percent complete: 50%

Barriers and Targets

- Vehicle light-weighting
- Seatback: high-performance requirement due to safety under crash incident
- Replacement of current metal frame with lightweight composites

Budget

- DOE project funding: \$500K
- Partner's in-kind contribution: \$500K

Partners

- Ford Motor Company (Industry Partner)
Lead: Patrick Blanchard

Relevance / Objectives

Overall Objectives

To develop a novel manufacturing technique to produce lightweight car seats by combining AM and over-molding techniques.

VTO's Mission

Support research, development (R&D), and deployment of efficient and sustainable transportation technologies that will improve energy efficiency, fuel economy, and enable America to use less petroleum.

The new developed process will:

- Allow for new lightweight seat designs that cannot be achieved through any other conventional processing methods.
- Produce seats with **tailored microstructure and performance**.
- Explore an **in-line integration of sensing and smart systems** that will be used for process monitoring. The collected data will be used within an Artificial intelligence (AI) framework for discontinuous reinforced composite manufacturing processes in order to optimize the processing conditions and part performance.

Tasks

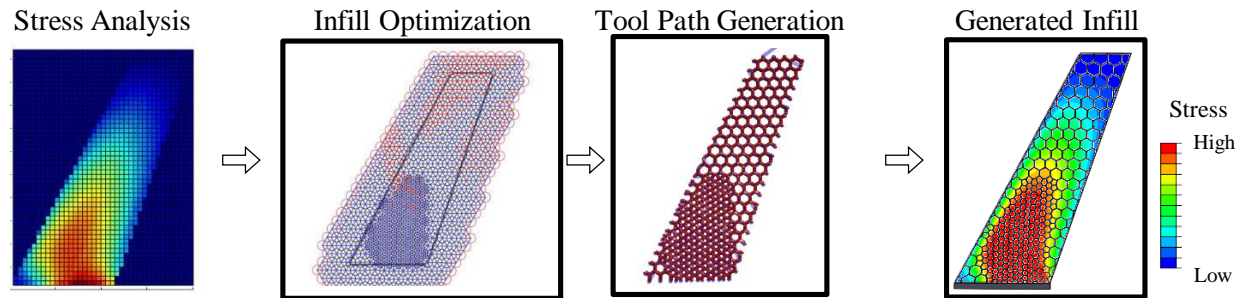
Stage I: Manufacturing of the seat back panel via large scale AM

- A preform from AM for a seat back panel with highly aligned fibers along the deposition direction.
- Multiple materials with different mechanical performances

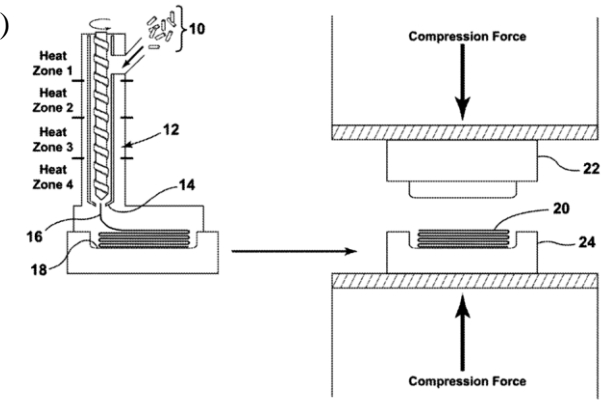
Stage II: Over-molding process – Integration of the seat back panel preform, molding of the reinforcement features, and placement of the metal inserts

Relevant Invention Disclosures/Patents

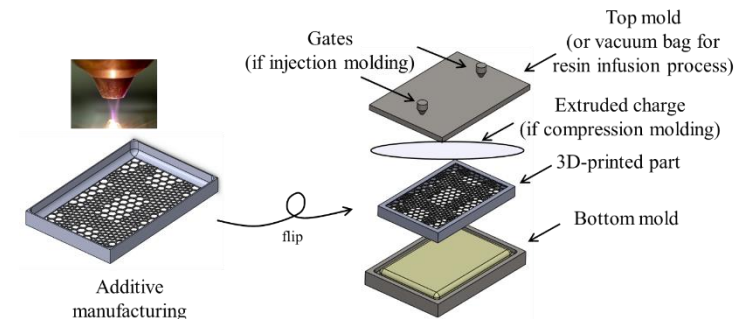
- UT-Battelle (UT-B) Invention Disclosure (ID) No. 4121, “Rapid manufacturing of tailored preforms”
- UT-B ID No. 3152, “Large Scale Polymer Additive Manufacturing and Carbon Fiber Layup Integration”
- UT-B ID No. 3151, “Method and Materials for Large Scale Polymer Additive Manufacturing”
- UT-B ID No. 201804272, “A Method for Rapid Manufacturing via Non-stop and Continuous Deposition in Additive Manufacturing by Adding Bridges in Toolpath”
- UT-B ID No. 202004563, “Over-molding on an Additively Manufactured Skeleton” ⁽³⁾
- UT-B ID No. 201904506, “Graded Honeycomb for Additive Manufacturing” ⁽²⁾
- UT-B ID No. 4278, “Manufacturing of insert skins for tooling”
- Patent US 2020/0023556 A1, “Rapid Manufacturing Of Tailored Preforms” ⁽¹⁾



Graded Honeycomb ⁽²⁾



AM - CM Process ⁽¹⁾



Over-molding on an AM Skeleton ⁽³⁾

Milestones

Phase No.	TaskNo.	Task Name	Duration (Months) (Start) (Finish)		Responsible Party
I	1	Project planning and management	0	24	Ford Motor Company/ORNL
I	2	Establish the required properties and the design aspects for the car seat	0	1	Ford Motor Company
I	3	New lightweight seat design through topology optimization	1	8	Ford Motor Company/ORNL
I	4	AM metal inserts for the recliner connection	4	8	ORNL
II	5	Mold manufacturing for sub-elements of seat assembly	9	13	Ford Motor Company/ORNL
II	6	Sub-component manufacturing	13	16	Ford Motor Company/ORNL
II	7	Characterization of the molded design features	15	19	ORNL
II	8	Exploration of integrating smart sensing system and framework for AI technology	13	22	Ford Motor Company/ORNL
II	9	Final performance and business evaluation of the seat assemblies	21	24	Ford Motor Company

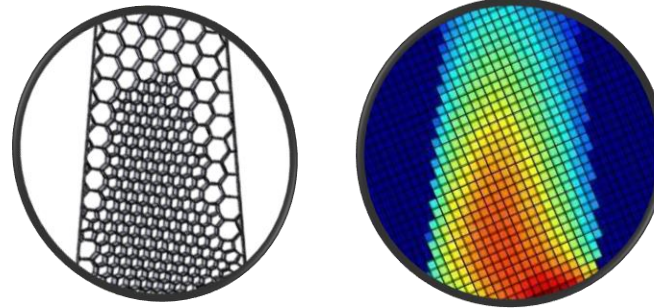
PROGRESS

Some delays in experimental activities have been experienced due to accessibility to laboratories during COVID

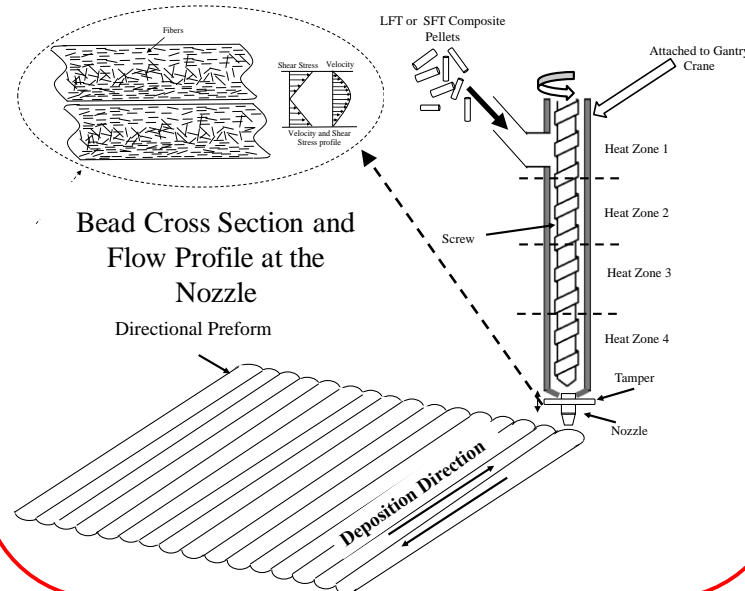
Approach

- Design Optimization & Evaluation
 - Adaptive lattice generation
 - Topology optimization
 - Assisted by simulation
- AM Preform
 - Fiber orientation control
 - Tailored toolpath direction
- AM – CM Process
 - Strengthening via void reduction
- Composite Over-molding
 - Maximize the advantages from dissimilar materials (e.g., Metal / composite)

Adaptive Core Technology for Topology Optimization of IM/CM Mold



Using Large Scale AM for Preform



Seat Back Reinforcement Ribs Panel

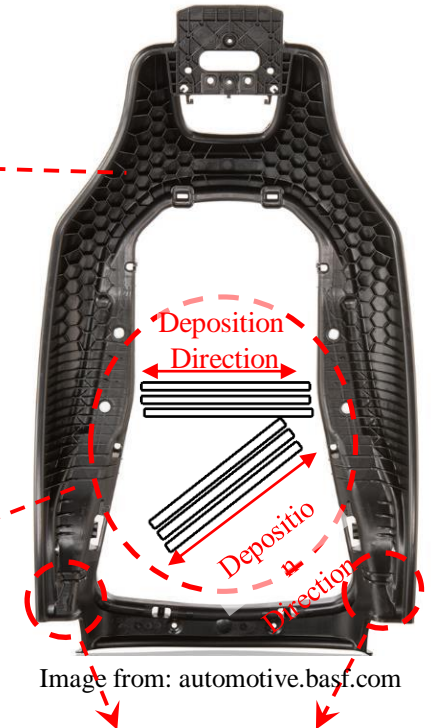
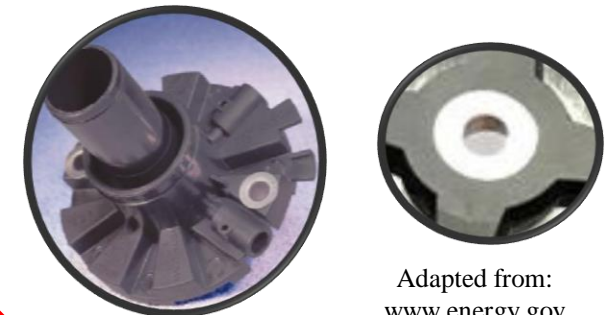


Image from: automotive.basf.com

Over Molding of Metal Inserts for Recliner Connections



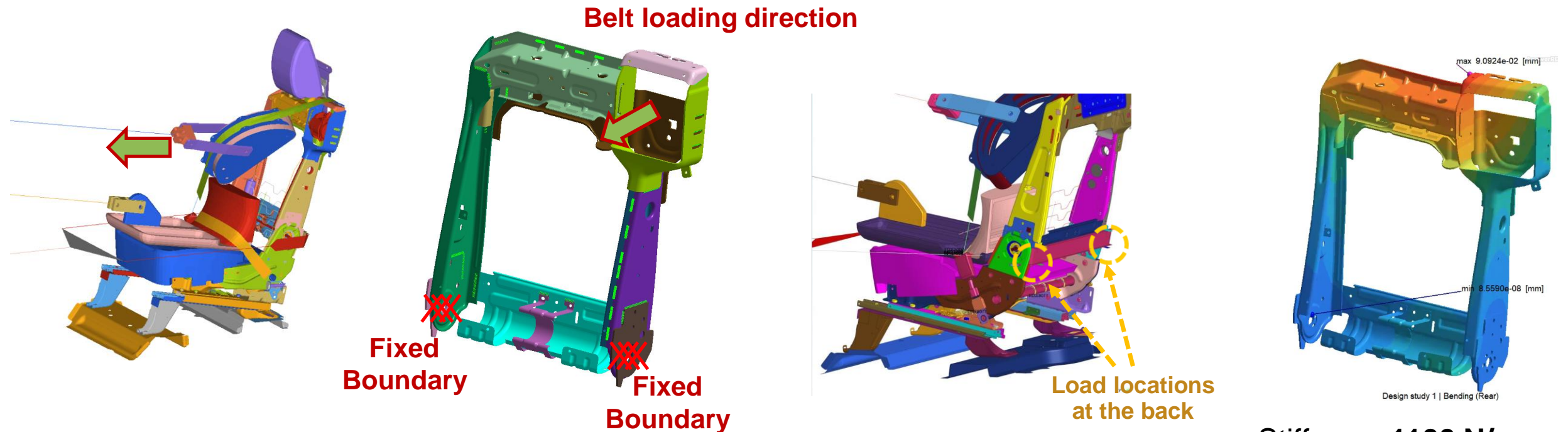
Adapted from:
www.energy.gov

Accomplishments: Boundary and Load Conditions

➤ Loads on the seatback frame design

- 7 loads on the seatbelt unit (passenger movement)
- Anchored at the bottom
- Other loads not on the seatback are excluded.

	Locations			Vectors		
	x (m)	y (m)	z (m)	V _x	V _y	V _z
Load 1	3.510	-0.522	1.358	-0.234	0.105	0.059
Load 2	3.510	-0.527	1.358	-0.236	0.105	0.058
Load 3	3.503	-0.585	1.360	-0.251	0.110	0.051
Load 4	3.503	-0.580	1.360	-0.250	0.110	0.050
Load 5	3.510	-0.642	1.358	-0.268	0.112	0.068
Load 6	3.510	-0.637	1.358	-0.266	0.112	0.067
Load 7	3.500	-0.574	1.255	-0.206	0.092	0.072

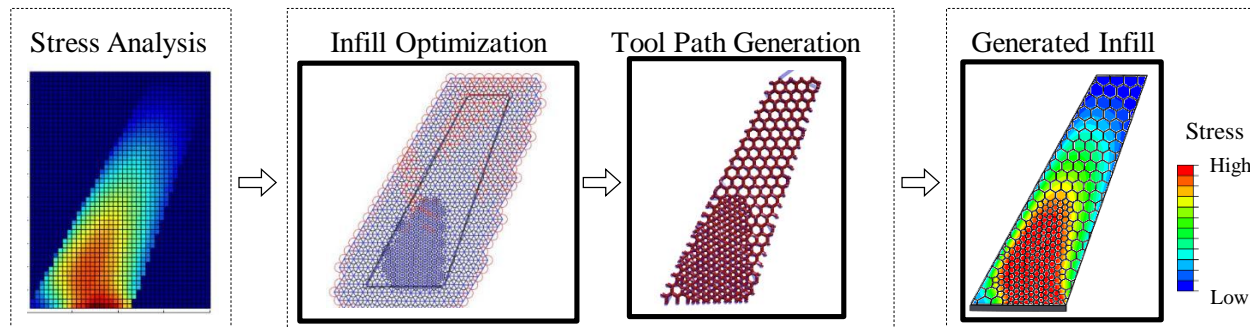
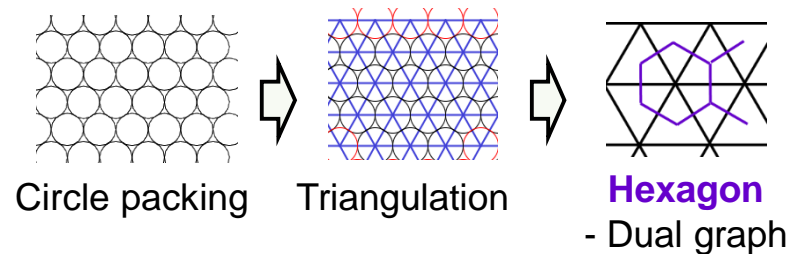


Stiffness: 1100 N/mm

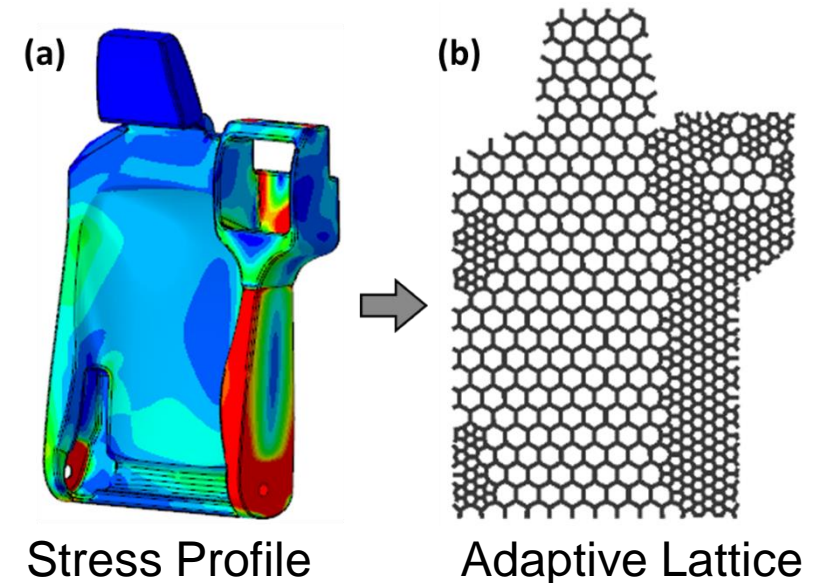
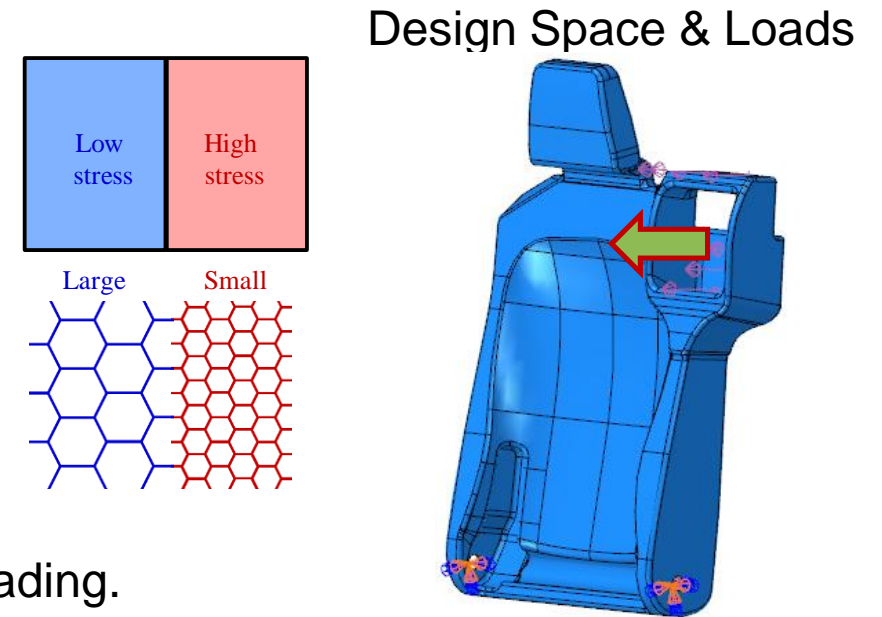
Accomplishments: Design Optimization /Adaptive Lattice Generation

- Design space
 - Entire space that can be used for optimal structure
- Stress prediction
 - Finite element analysis (FEA) to identify the stress profile
- Graded lattice generation for seatback panel
 - Finer lattice for a high stress area
 - Non-uniform lattice: connectivity issue
 - Circle packing algorithm to ensure the connectivity

The proposed approach is not most optimal for cantilever beam-type loading.



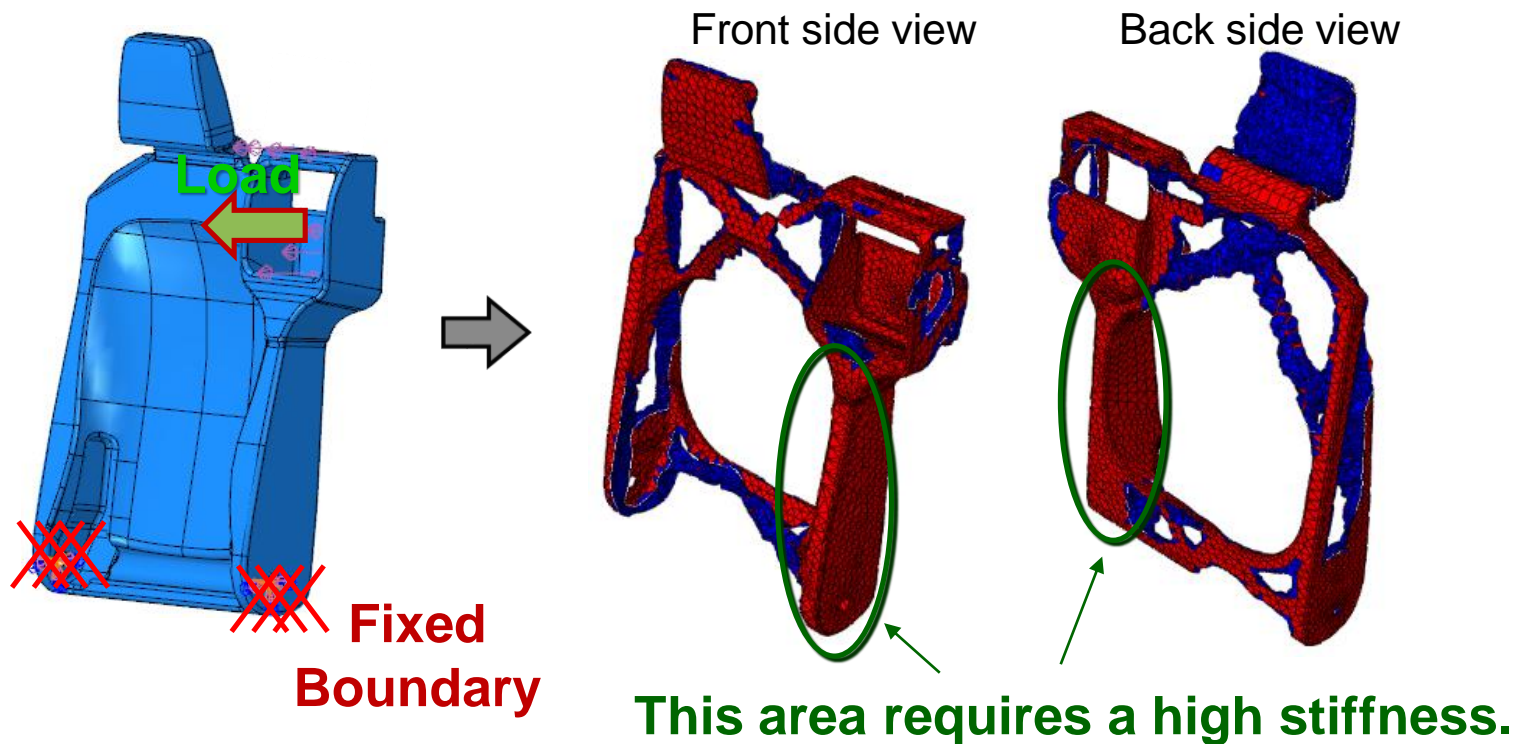
Adaptive Lattice Generation



Accomplishments: Design/Topology Optimization

➤ Topology optimization

- Iterative process between a finite element method calculation and removal of volumes where their stress levels are lower than a prescribed threshold.
- Significant reductions (> 50%) for most of the locations except the left side column which requires the highest stiffness.



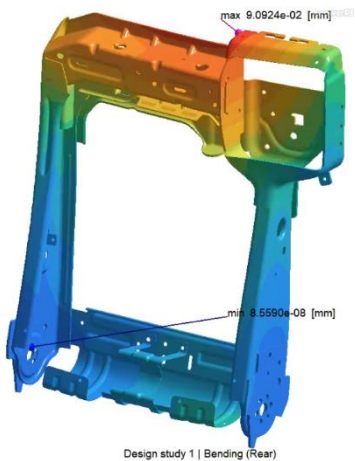
Topology optimized
Polymer/fiber composite is
not stiff enough to replace a
metal frame.



Progress: Stiffness Comparison

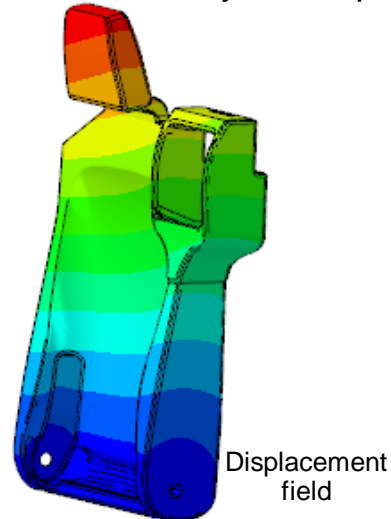
- Composite alone does not provide enough stiffness.
 - Composite with a fully filled space: 260 – 320 N/mm vs. Metal: 1100 N/mm
- Composite combined with a metal insert significantly increases the stiffness.
 - 320 N/mm (w/o metal) → 930 N/mm (w/ metal)
- Optimization of metal insert highly affects the stiffness.

Metal frame



Stiffness: 1100 N/mm

Composite with fully filled space



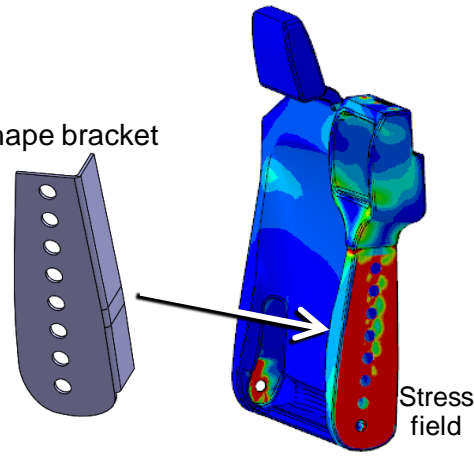
Stiffness: 260 N/mm (ABS/CF20)

Stiffness: 320 N/mm (PA/CF30)

- Modulus of steel: 200 GPa
- Modulus of PA/CF30 (x-direction): 19 GPa

Metal insert + Composite

L-shape bracket

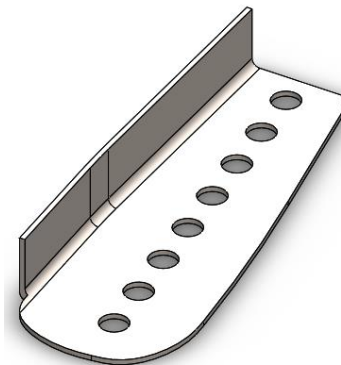


(PA/CF30)

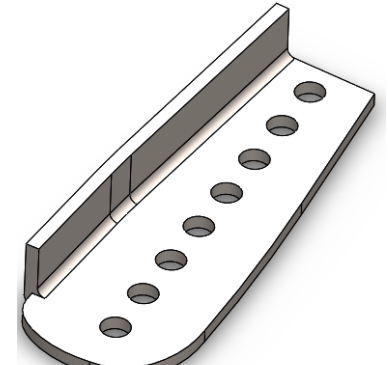
Stiffness: 930 N/mm

Effect of L-shape bracket thickness

	Stiffness
4mm-thick	930 N/mm
10mm-thick	1640 N/mm



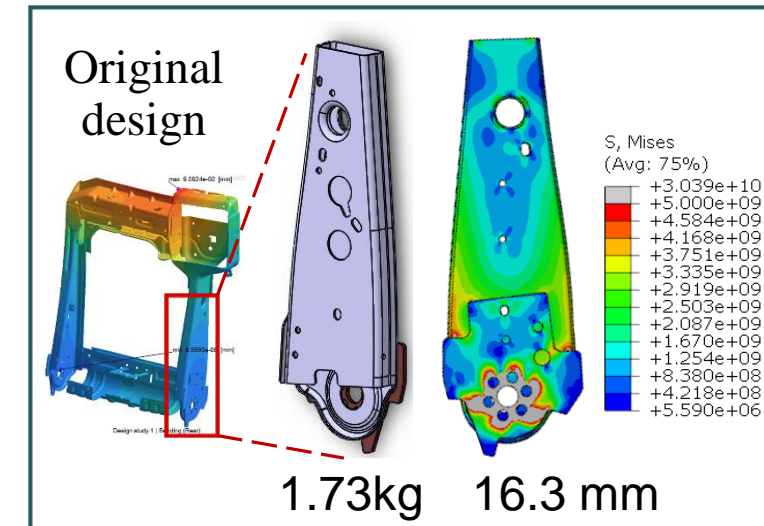
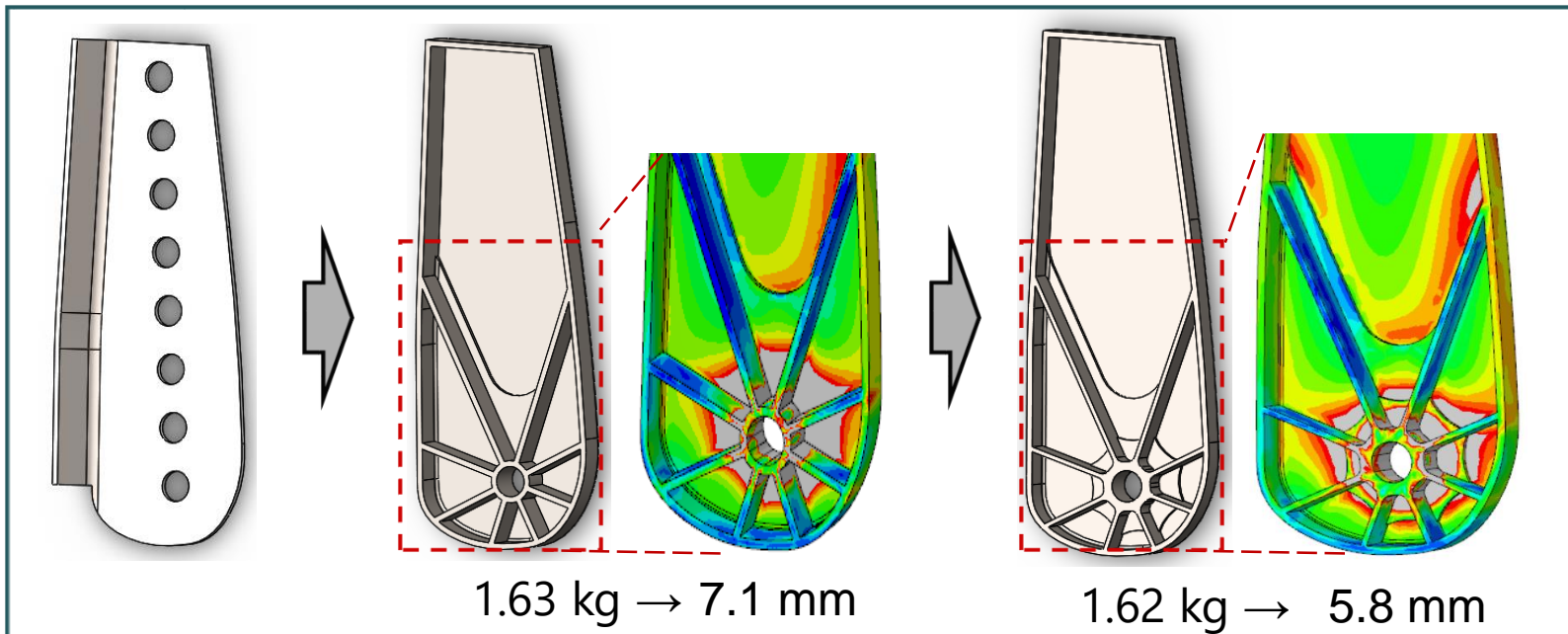
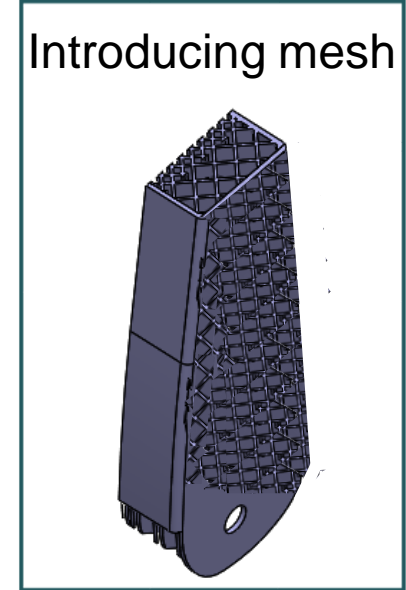
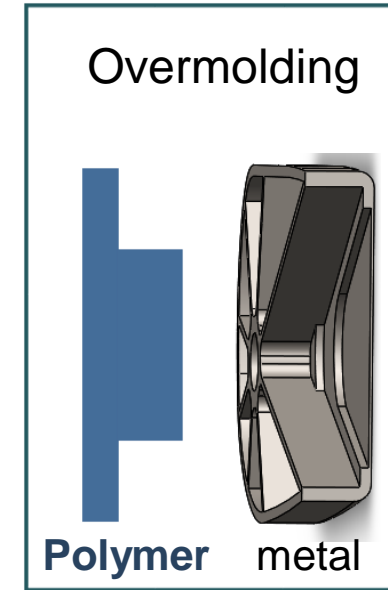
4 mm



10 mm

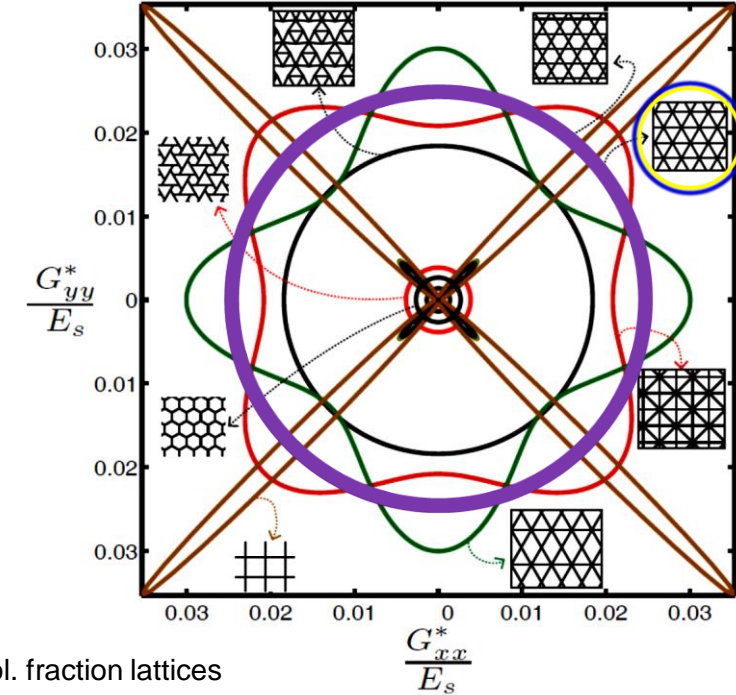
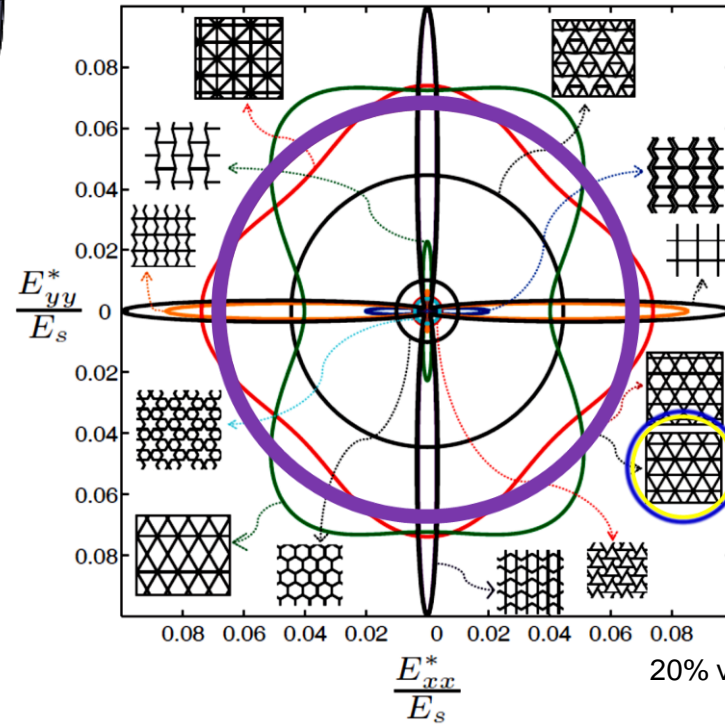
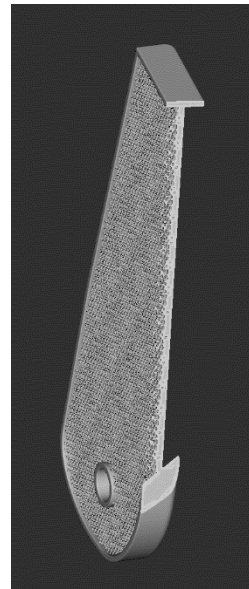
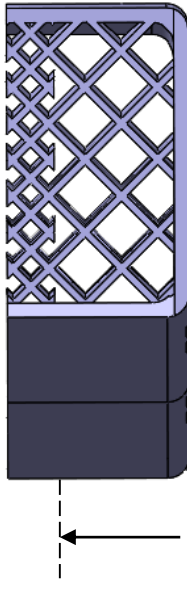
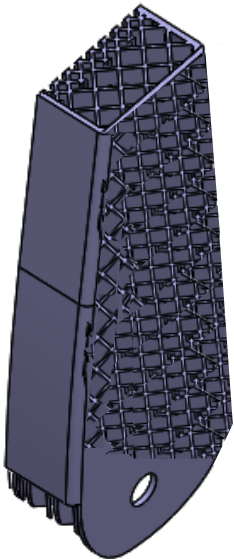
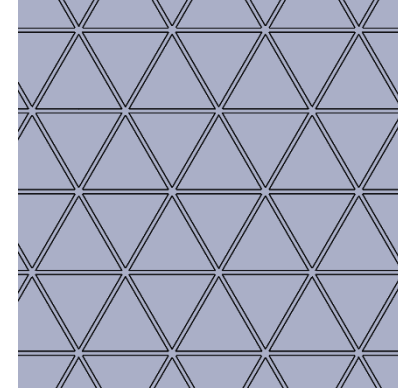
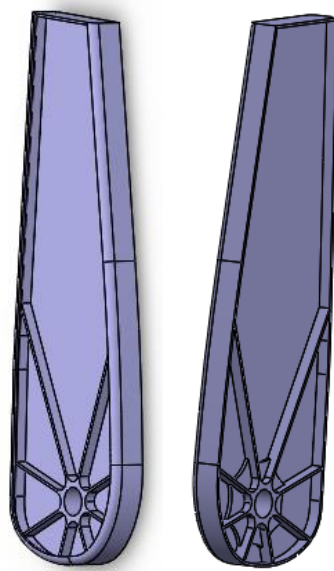
Progress: Design Optimization – Metal Bracket

- Bracket design optimization
 - Multiple iterations b/w CAD modification and FEA simulation
 - The new design shows a significantly higher stiffness than the original design
- Mesh for over-molding
 - Reduces the amount of polymer (blocking the flow)
 - Provides stronger mechanical bonding → Joining dissimilar materials
 - Adds additional stiffness



Progress: Design Optimization – Mesh on the Bracket

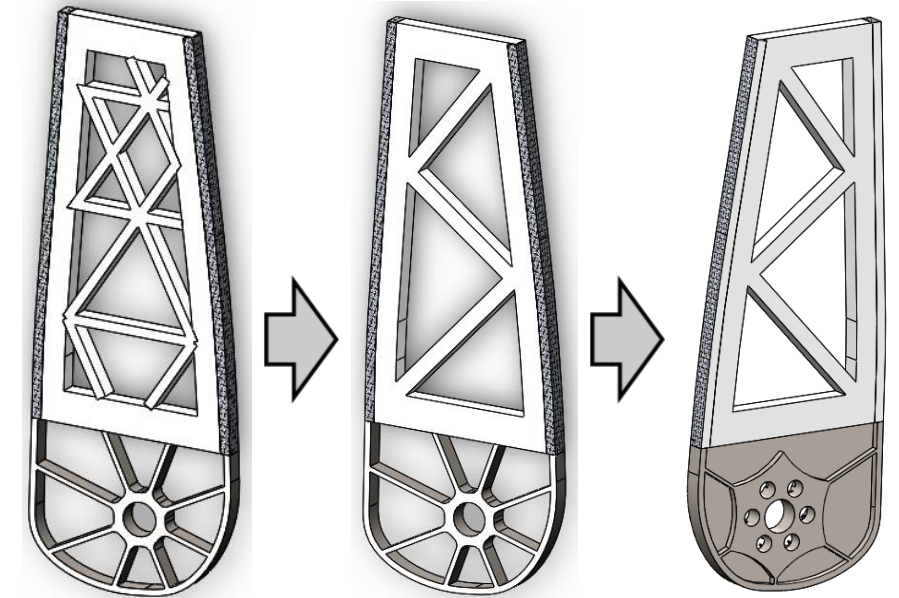
- Iteration process
 - Two mesh sizes
 - Mid plate (I-beam type)
 - Mesh on one side
- Mesh shape effect
 - Iso-grid (equilateral)



Ref) "Effective Mechanical Properties of Lattice Materials" by Prateek Chopra, Master's thesis, Univ. of British Columbia

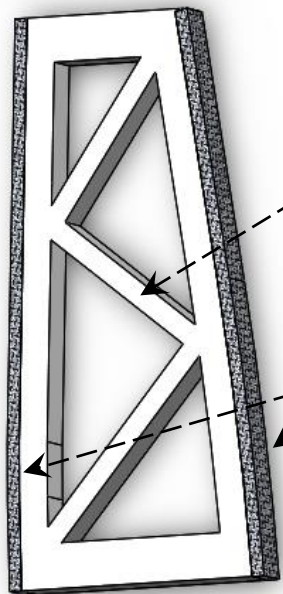
Progress: Composite + Metal Bracket

- Composite over-molding – Design change
 - Multiple iterations
- Three components
 - Metal insert
 - Uni-tape
 - AM preform long fiber thermoplastic
 - Fiber direction along the strut direction (deposition direction)



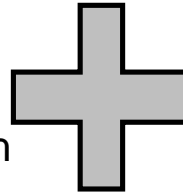
1.45 kg
7.6 mm

Polymer composite for over-molding

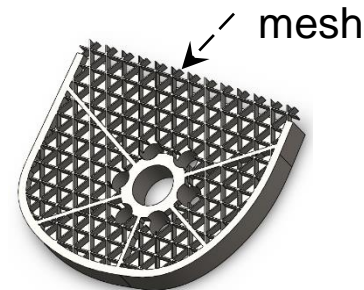


Long fiber thermoplastic
made from AM preform
with tailored directions

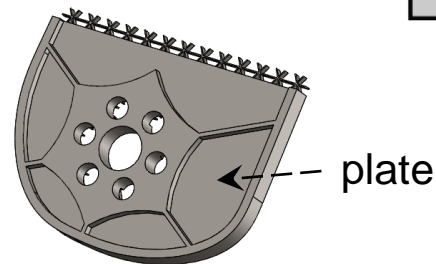
Polymer reinforced with
uni-directional fibers



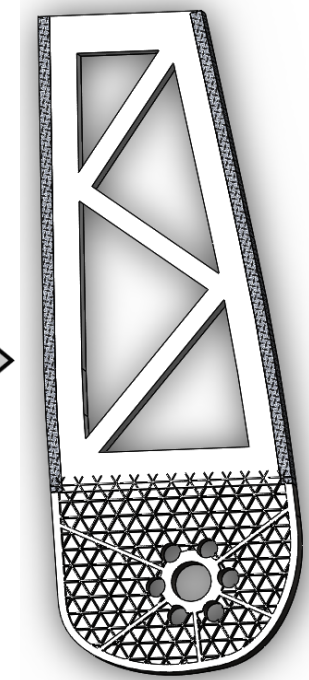
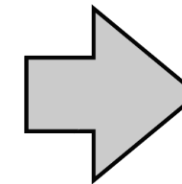
3D printed metal insert



Inner side view



Outer side view

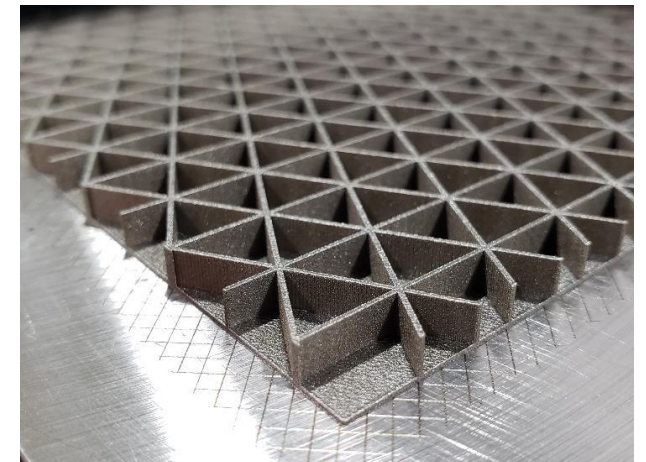
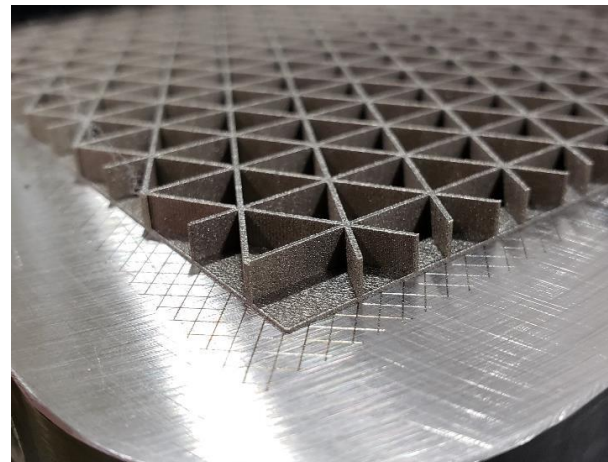
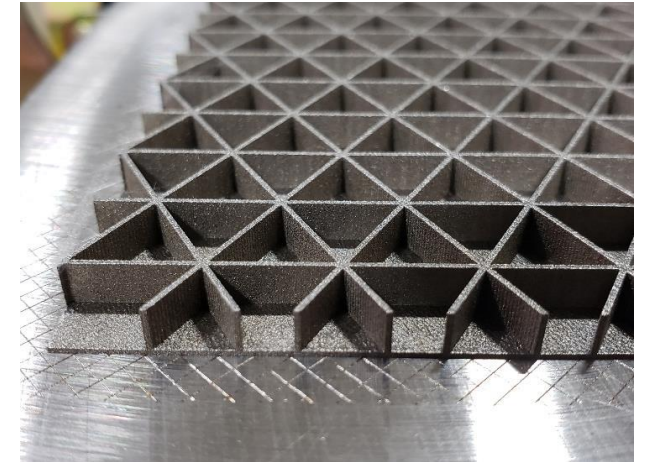
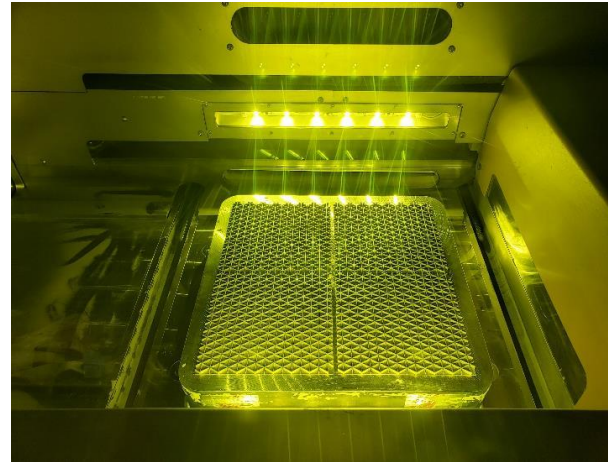


Progress: Sample Panel Fabrication

- In order to check the flowability into mesh
- AM Preform (CF/PA66)
 - Long fiber printing (0.5" CF)
 - High loading fiber (40% CF)--> Process calibration for stable printing (e.g., Temp zone, federate)

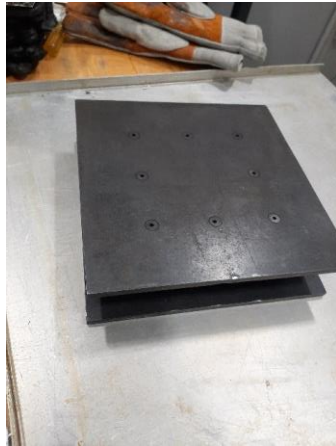


- Metal mesh
 - Metal powder system (AddUp) with maraging steel

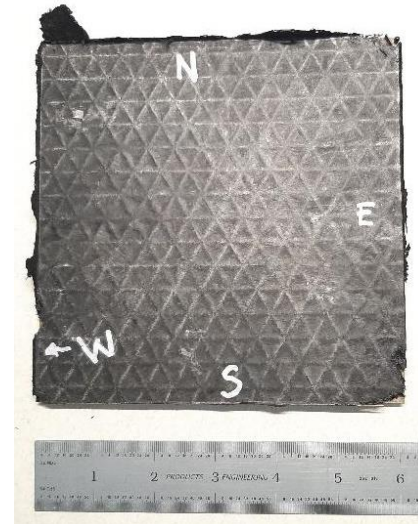


Progress: Over-molding a Sample Panel

- Over-molding onto a mesh
 - Metal Mesh + Polymer composite
 - Joining dissimilar materials without bonding agent
 - Thermoplastic characteristics (Printing a shape --> re-heating --> molding)



Front



Back



Check Bonding (Flowability)

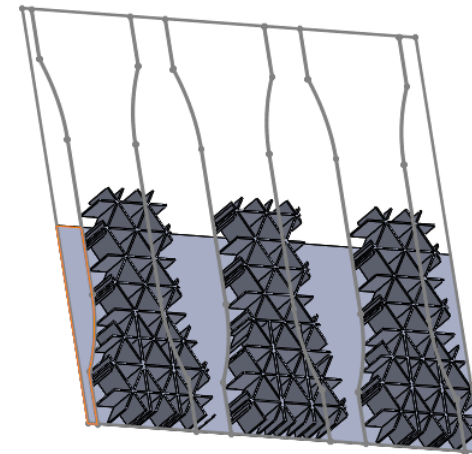
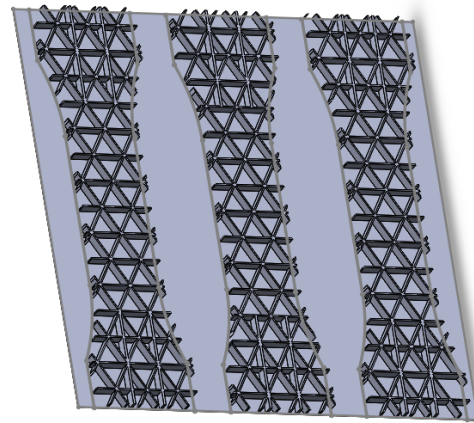
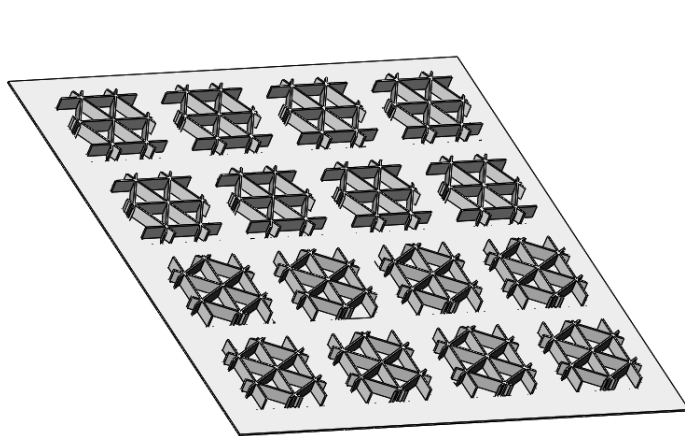
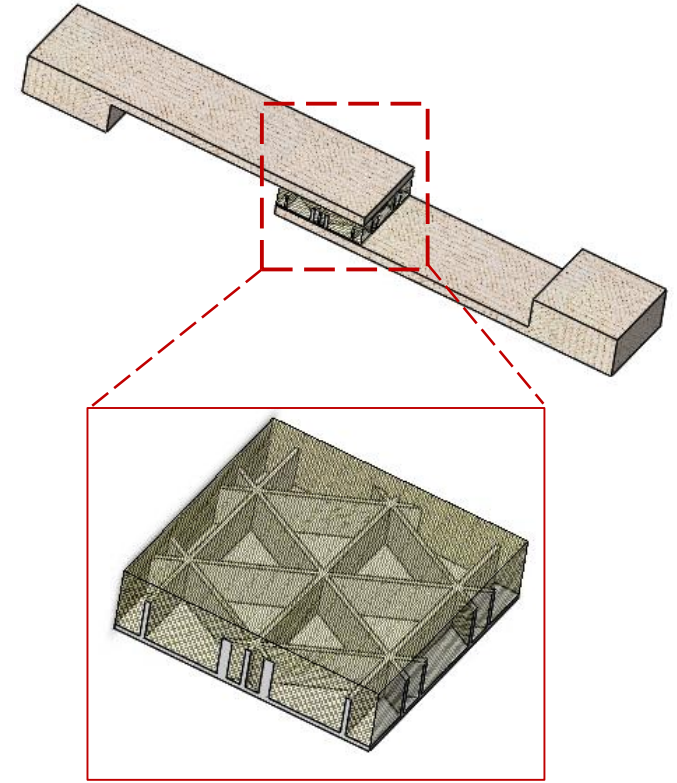
- Cross-section view
 - Good bonding between metal and polymer
 - Fiber flow into the mesh



Microscope image

Bonding Property Measurement

- Mechanical Properties of Over-molded Part
 - Shear property for metal/polymer composite
 - Tensile property for metal/polymer composite
 - Tensile property for the interface between metal and polymer composite
- Properties for Simulation



Collaboration

- Ford Motor Company
 - Point of Contact: Patrick Blanchard (pblanch3@ford.com)
 - Ford Project Team Members
 - Patrick Maloney
 - Sangram Tamhankar
 - Rao Parameswararao
 - Ari Caliskan
 - Marc Konrad
 - Kevin VanNieulande
 - Sean West

Remaining Challenges

- Understanding the mechanical behavior and characteristics of the over-molded samples
- Optimization of the seat back design with viability of manufacturing in mind
- Utilization of AM process for the manufacturing of the subscale mold

Proposed Future Research

- Testing and analyzing of the over-molded samples (tensile, shear, and interlayer)
- Reporting and documenting the findings – data will be used as an input for the FEA model
- Optimizing and finalizing the seat back design
- Selecting a subscale area of interest and design a subscale mold for manufacturing this area
- Manufacturing of the subscale mold
- Manufacturing and testing of the subscale composite component
- Exploring and testing In-line integration of sensing and smart systems process monitoring. Data to be used within an Artificial intelligence (AI) framework for manufacturing processes.

Any proposed future work is subject to change based on funding levels

Summary

- Develop a novel manufacturing technique to produce lightweight car seats by combining AM and over-molding techniques
- Initial new seat designs, via topology optimization, that cannot be achieved through any other conventional processing methods
- Design optimization via FEA simulation – design modification
- Using AM to manufacture recliner metal brackets to be integrated with the composite preform via over-molding process
- Validation of the proof of concept of using AM mesh structures for joining in over-molded composites